Lecture 05

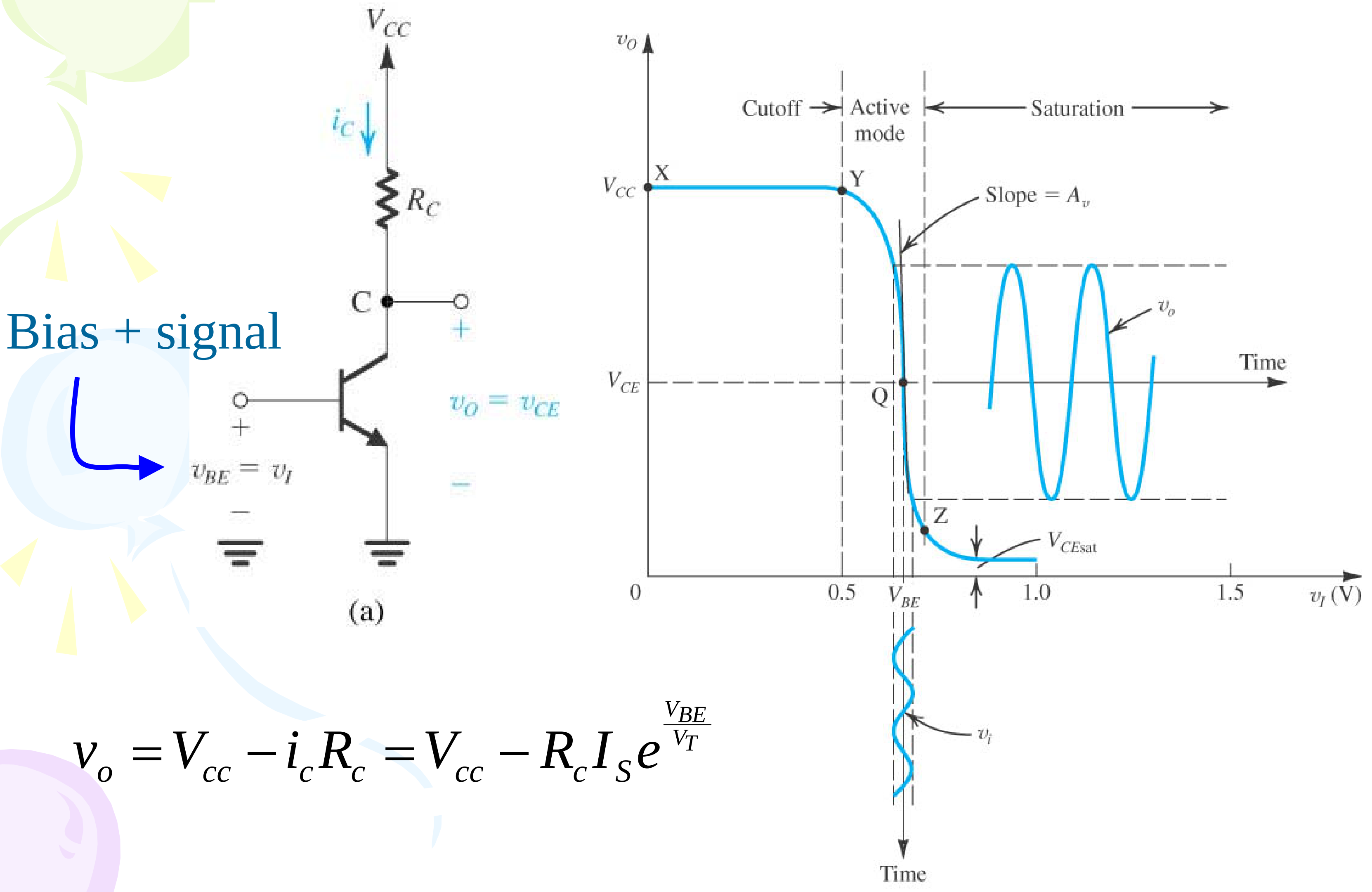
BJTs Circuits

topics

- Large-signal operation
- BJT circuits at DC
- BJT biasing schemes

Large-signal → Bias (DC) + signal (AC)

Bias + signal

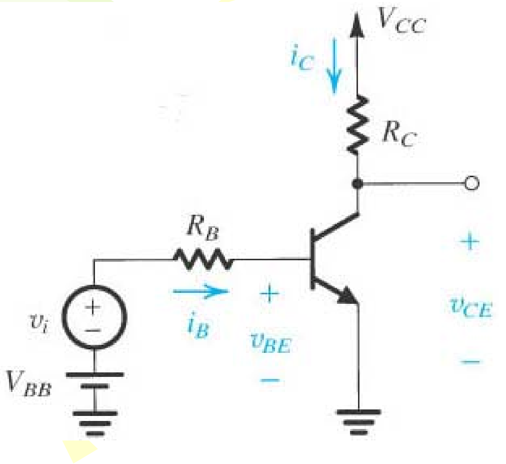


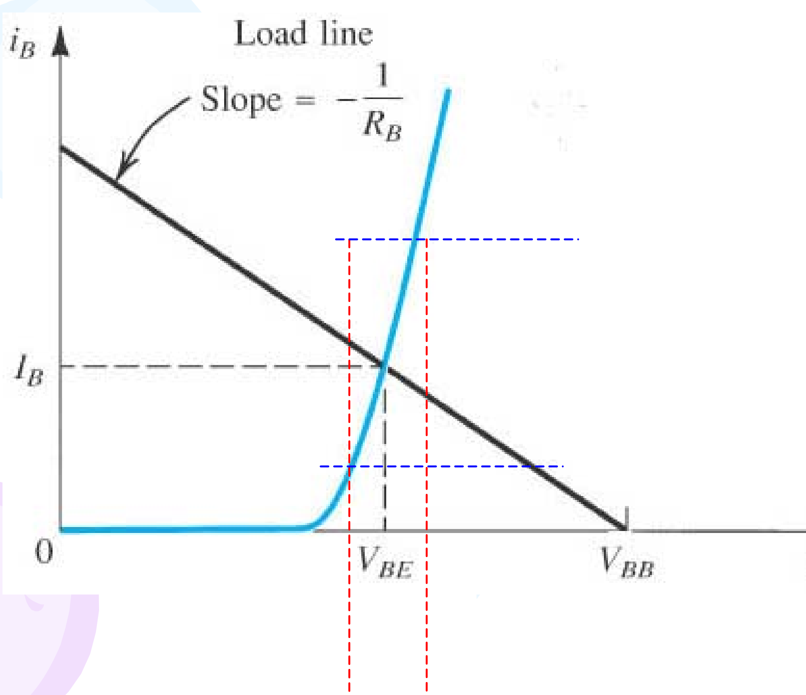
(a)

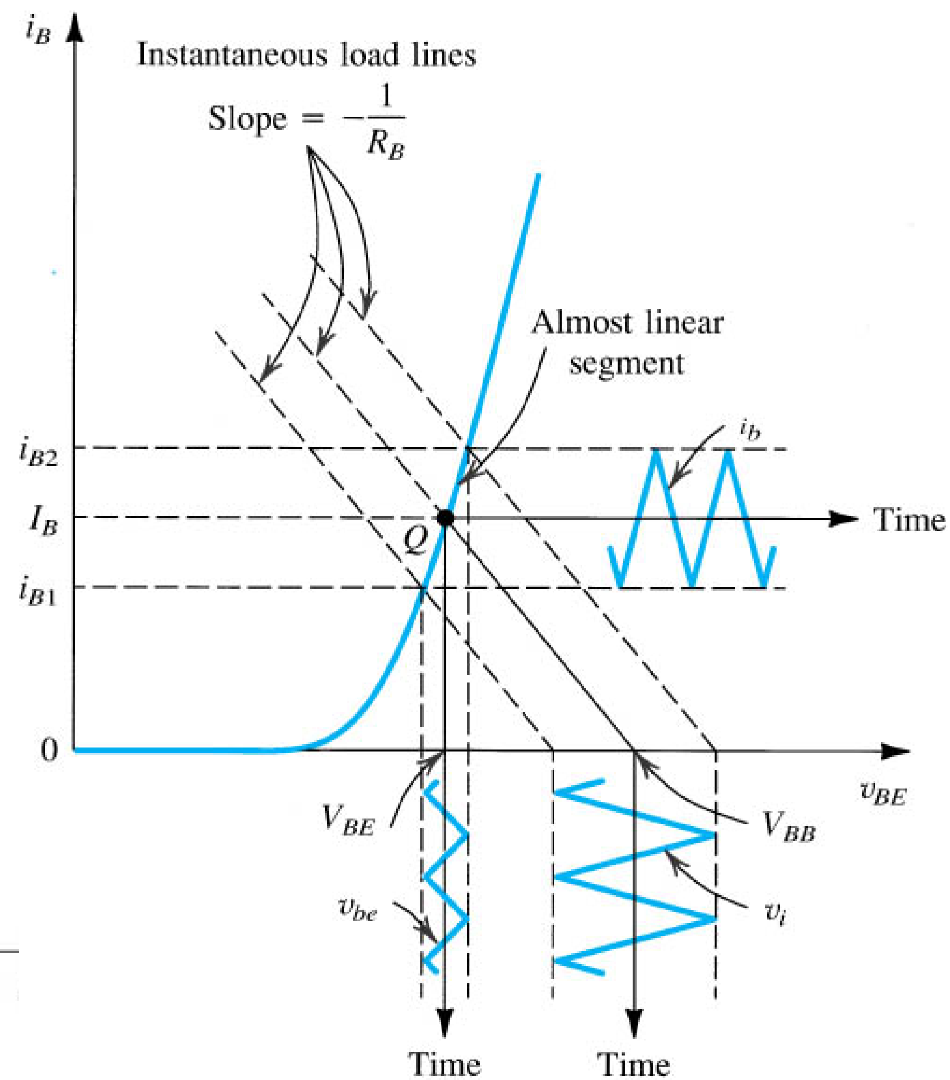
(b)

$$v_o = V_{cc} - i_c R_c = V_{cc} - R_c I_S e^{\frac{V_{BE}}{V_T}}$$

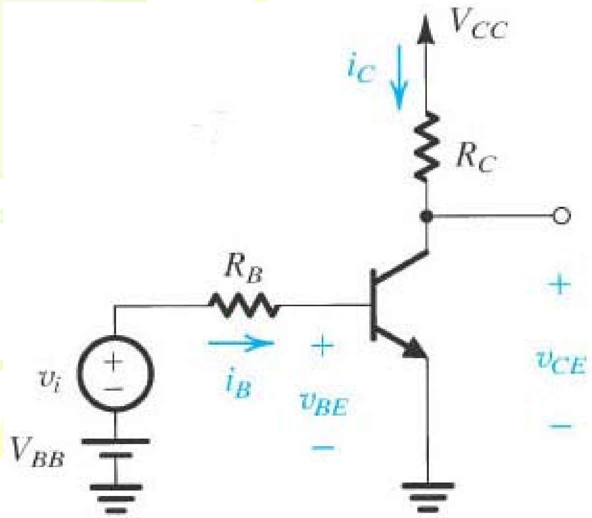
DC load line : $V_{BB} = I_B \times R_B + V_{BE}$



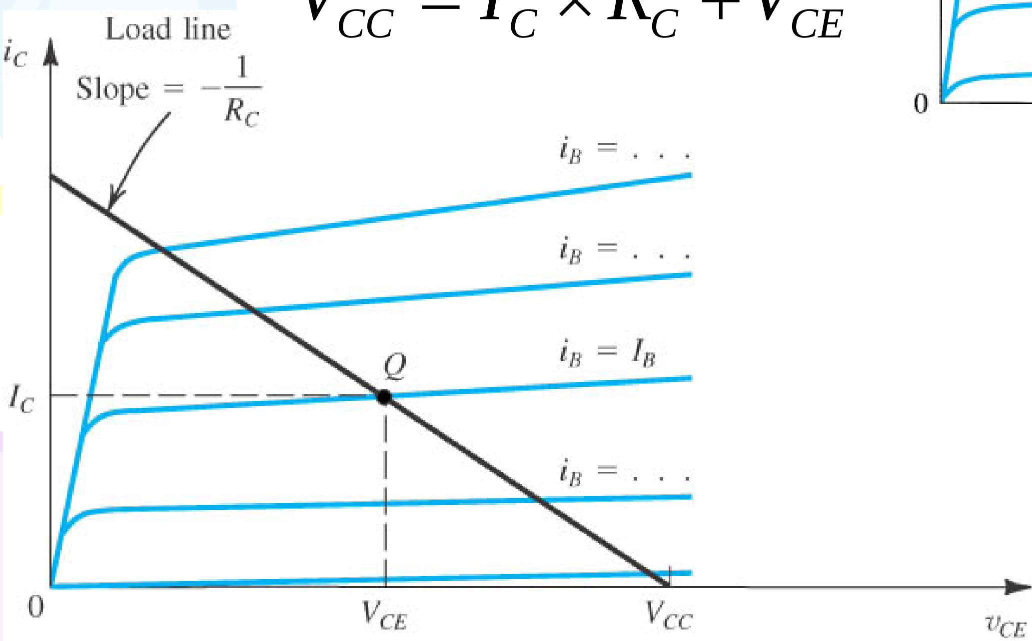


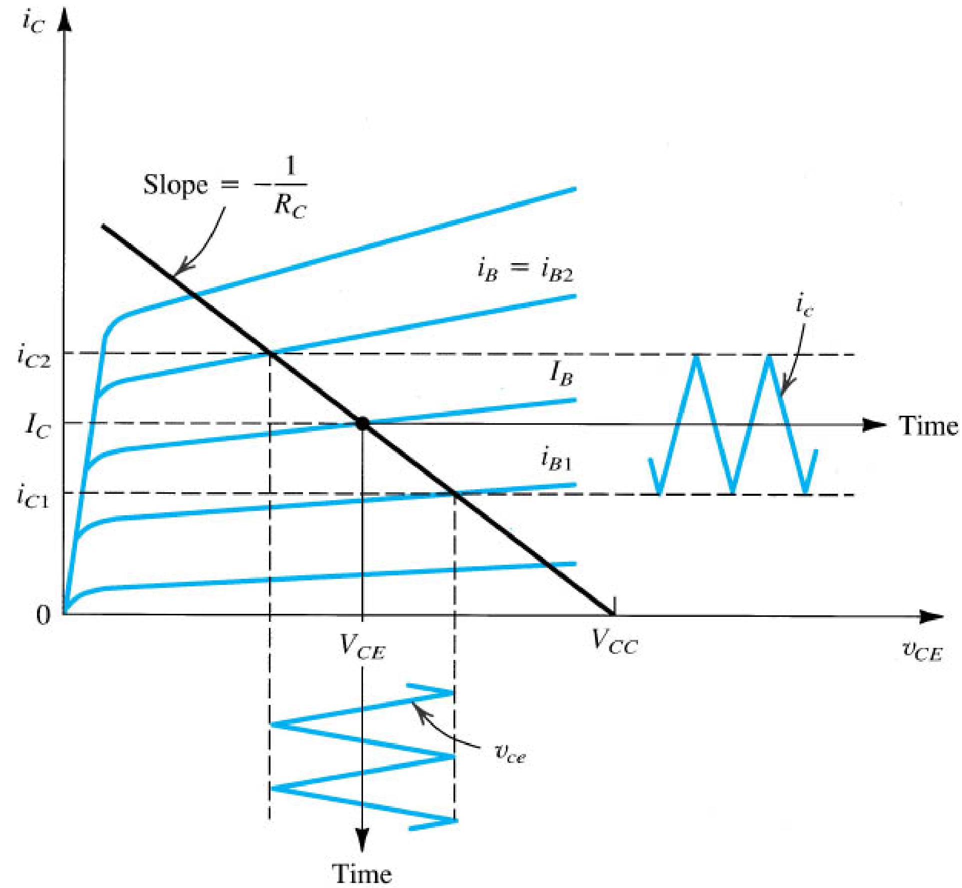


(a)

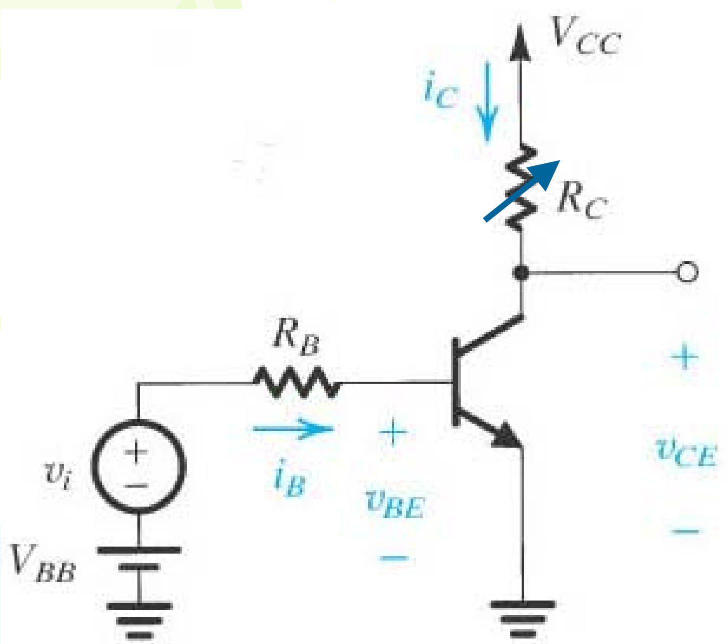


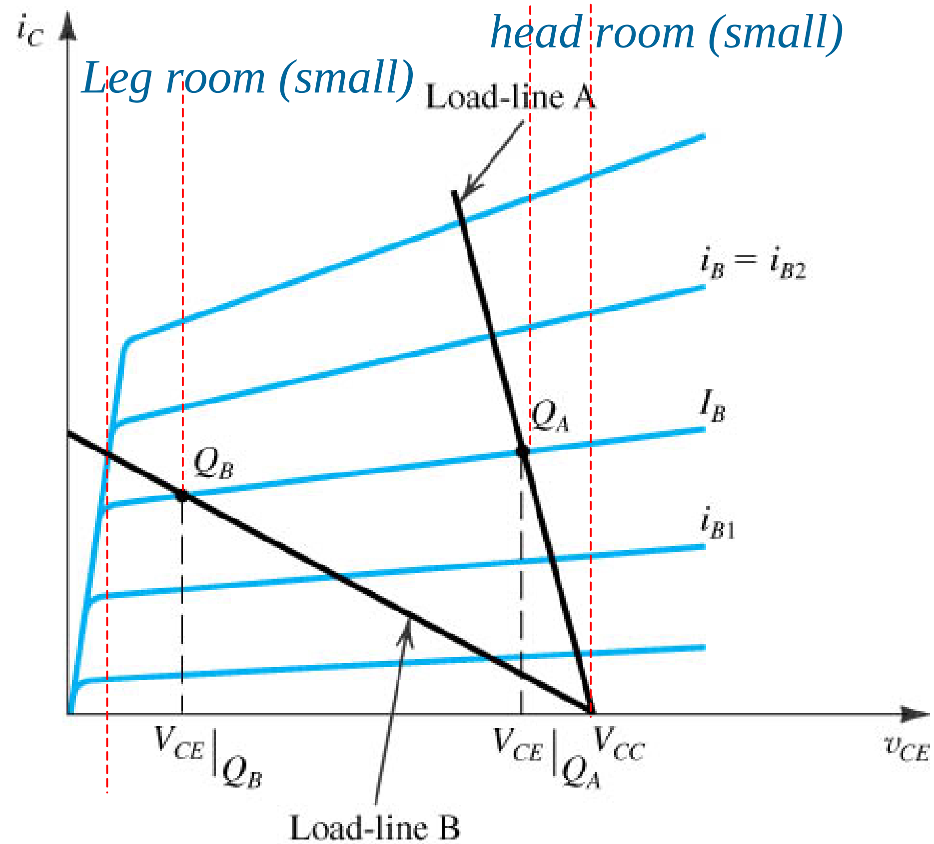
$$V_{CC} = I_C \times R_C + V_{CE}$$





(b)



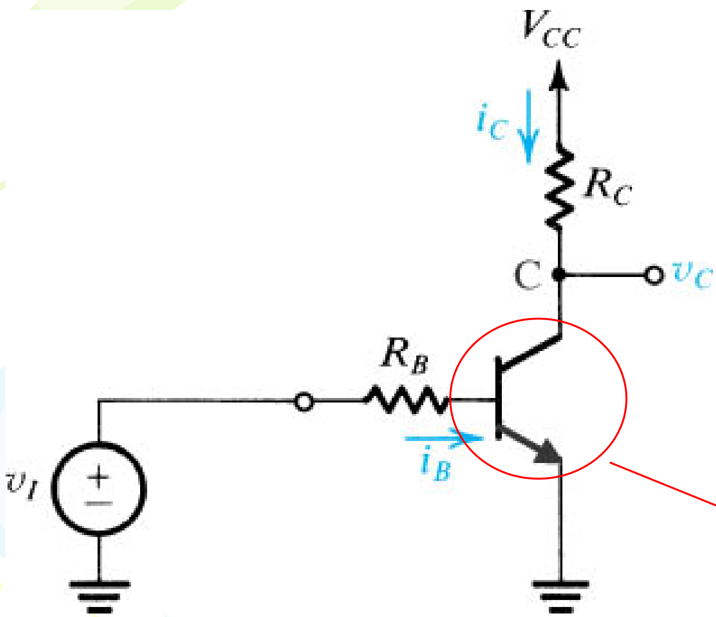


$$V_{CC} = I_C \times R_{CA} + V_{CE} \rightarrow Q_A$$

$$V_{CC} = I_C \times R_{CB} + V_{CE} \rightarrow Q_B$$

$$R_{CB} > R_{CA}$$

BJT operate as a switch

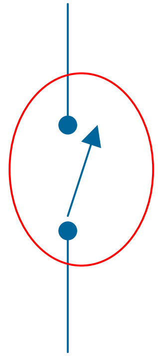


Switch off:

$$v_I < 0.5V \rightarrow i_B = 0 \rightarrow i_C = 0 \rightarrow v_C = V_{CC}$$

Switch on:

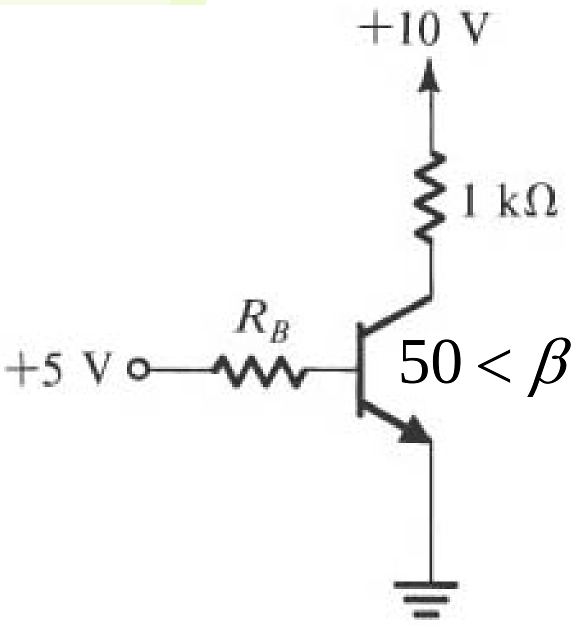
$$v_C = 0.2V \approx 0V$$



Switch on → saturation mode
Switch off → cut-off mode

Example 5.3

BJT work in saturation mode



$$50 < \beta < 150$$

$$V_C = V_{CE(sat)} = 0.2V$$

$$I_{C(sat)} = \frac{10-0.2}{1k} = 9.8mA$$

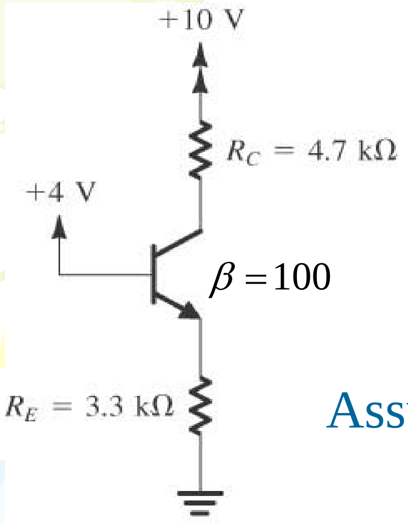
$$I_{B(\max)} = \frac{I_{C(sat)}}{\beta_{\min}} = \frac{9.8m}{50} = 0.196mA$$

$$I_{B(\min)} = \frac{I_{C(sat)}}{\beta_{\max}} = \frac{9.8m}{150} = 0.0653mA$$

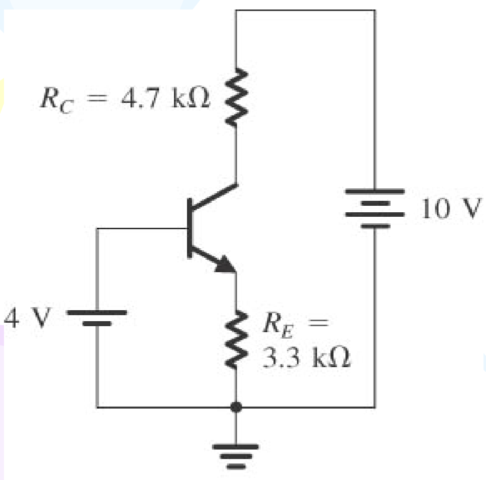
$$I_B = I_{B(\max)} \times overdrive \quad factor$$

$$R_B = \frac{5-0.7}{I_B} = \frac{4.3}{1.96} = 2.2k$$

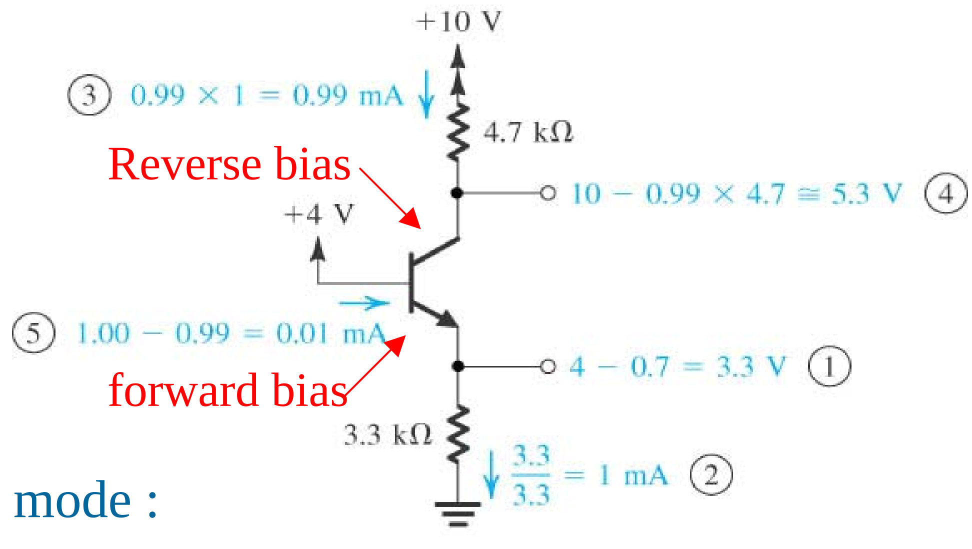
Example 5.4 (DC analysis)



(a)



(b)



(c)

Assume BJT in active mode :

$$V_E = 4 - 0.7V = 3.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{3.3}{3.3k} = 1mA$$

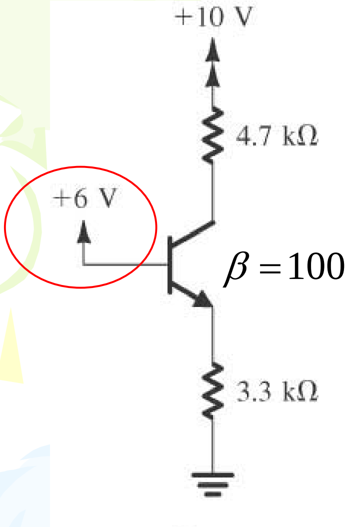
$$I_C = \alpha I_E = \frac{100}{100+1} \times 1mA = 0.99mA$$

$$I_B = I_E - I_C = 0.01mA$$

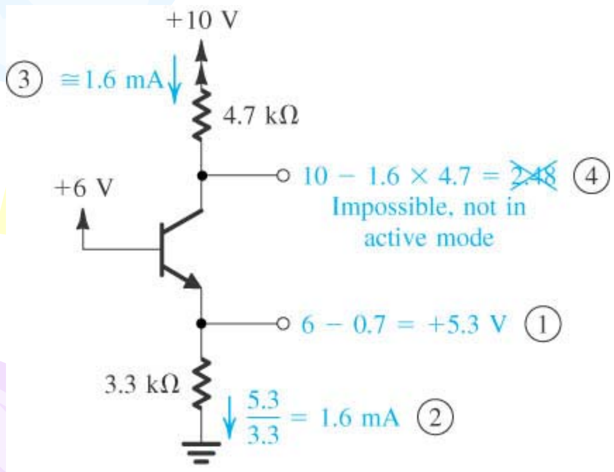
$$V_C = 10 - I_E \times 4.7k = 5.3V$$

Active mode check

Example 5.5 (DC analysis)



(a)



(b)

Assume BJT in active mode :

$$V_E = 6 - 0.7V = 5.3V$$

$$I_E = \frac{V_E}{R_E} = \frac{5.3}{3.3k} = 1.6mA$$

$$I_C = \alpha I_E = \frac{100}{100+1} \times 1.6mA = 1.584mA$$

$$I_B = I_E - I_C = 0.016mA$$

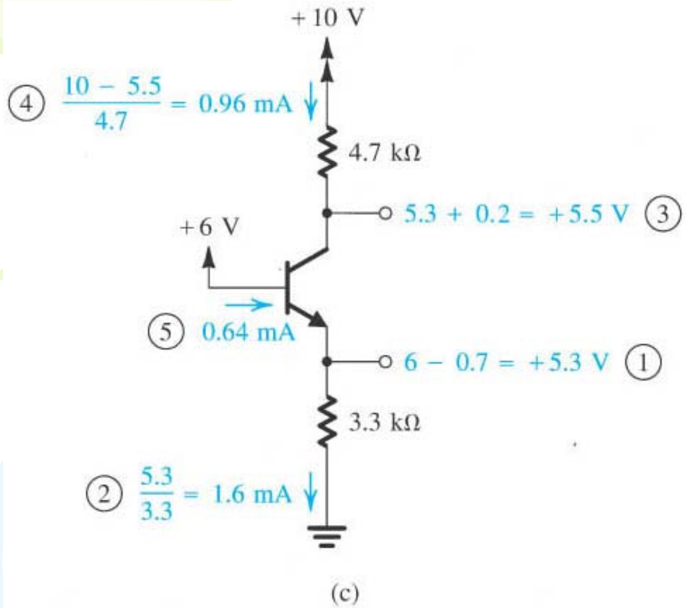
$$V_C = 10 - I_E \times 4.7k = 2.48V$$

JC : forward bias

JE : forward bias

Not in active mode

Assume BJT in saturation mode :



$$V_E = 6 - 0.7V = 5.3V$$

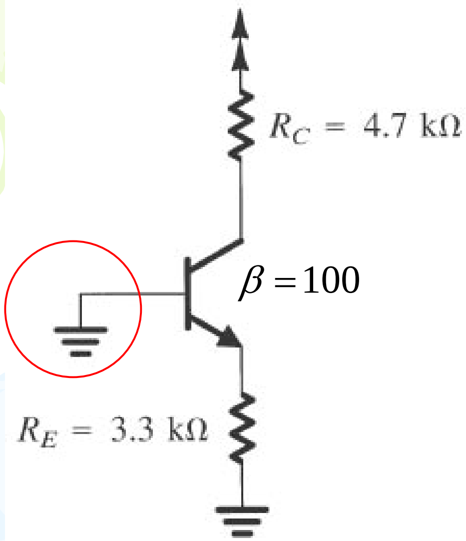
$$V_C = V_E + V_{CE(sat)} = 5.3 + 0.2 = 5.5V$$

$$I_E = \frac{V_E}{I_E} = \frac{5.3}{3.3m} = 1.6mA$$

$$I_C = \frac{10 - 5.5}{4.7} = 0.96mA$$

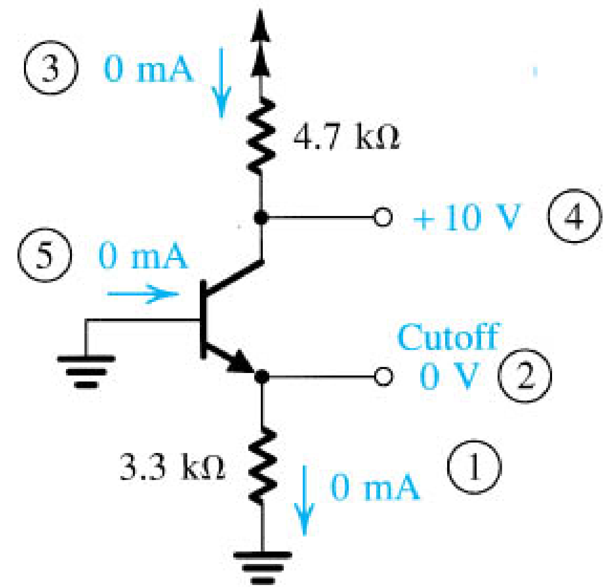
$$I_B = I_E - I_C = 0.64mA$$

Example 5.6 (DC analysis)



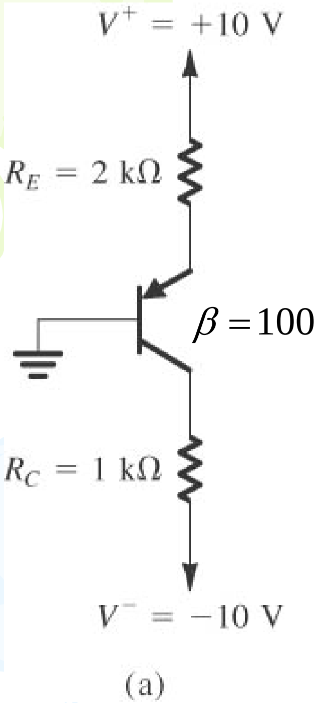
(a)

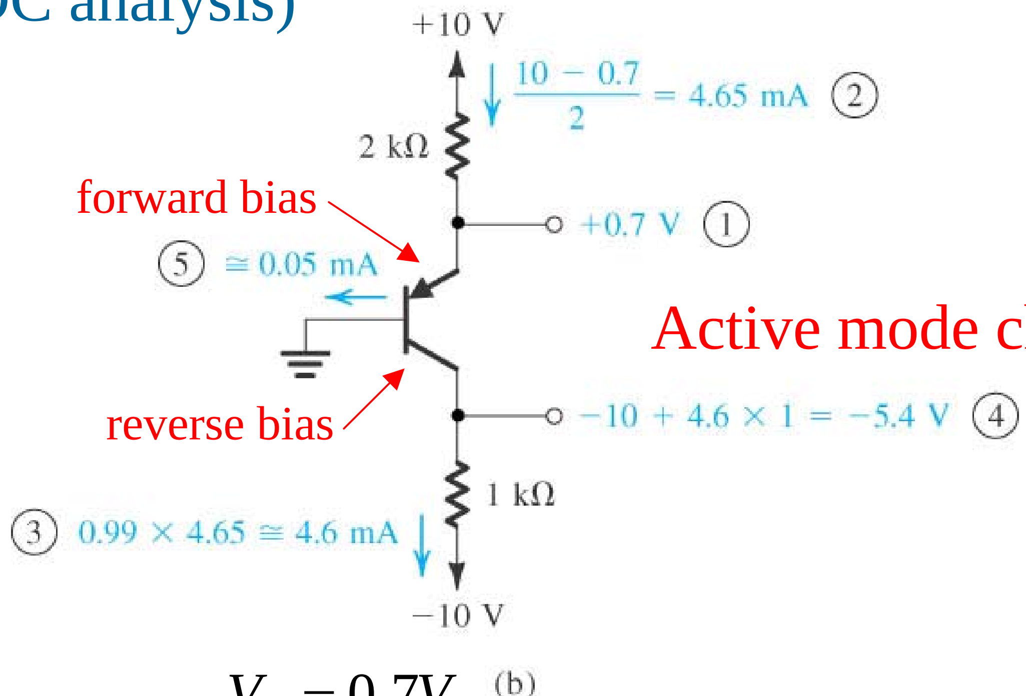
$$V_{BE} = 0V$$
$$I_B = 0mA$$
$$I_E = 0mA$$
$$I_C = 0mA$$
$$V_C = V_{cc} = 10V$$



(b)

Example 5.7 (DC analysis)





Active mode check

Assume BJT in active mode :

$$V_E = 0.7V$$

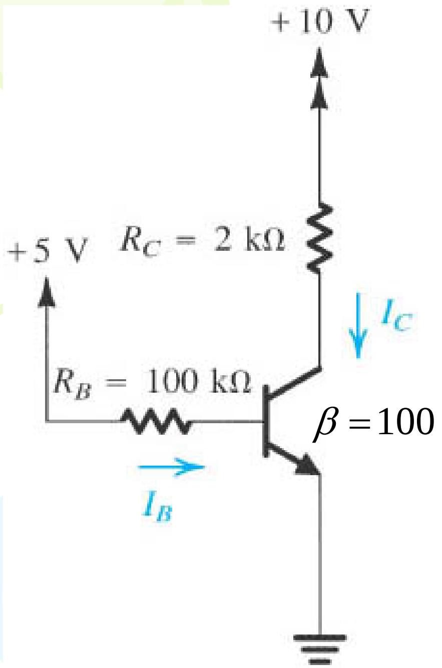
$$I_E = \frac{10 - 0.7}{2k} = 4.65mA$$

$$I_C = \alpha I_E = \frac{100}{101} \times 4.65m = 4.6mA$$

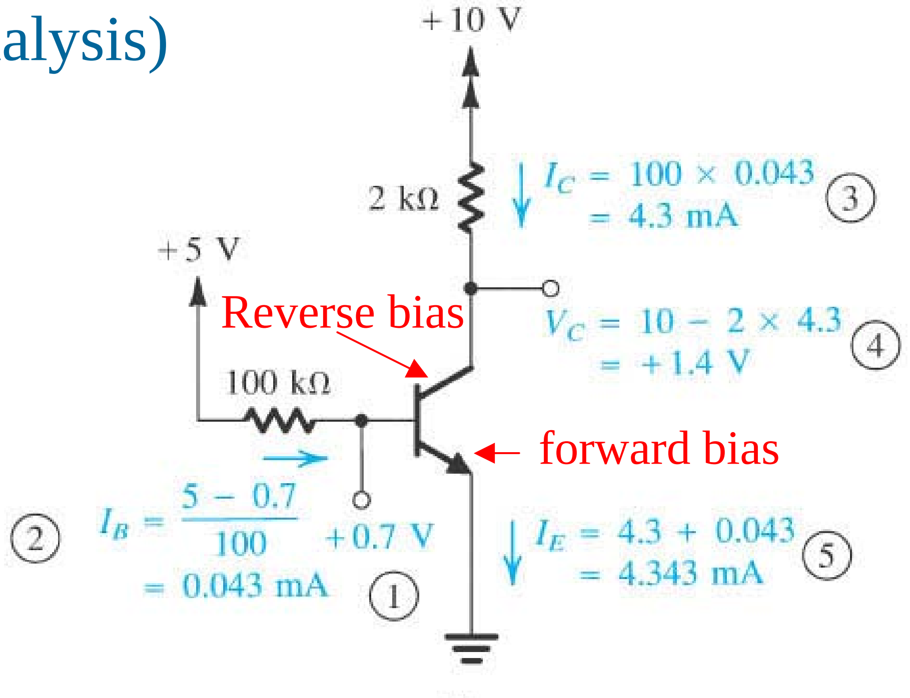
$$V_C = I_C \times R_C - 10V = 4.6m \times 1k - 10 = -5.4V$$

$$I_B = I_E - I_C = 0.05mA$$

Example 5.8 (DC analysis)



(a)



(b)

Assume BJT in active mode :

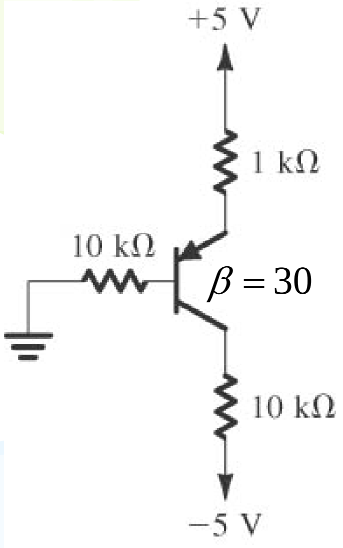
$$5V = 100k \times I_B + V_{BE} = 100k \times I_B + 0.7$$

$$\Rightarrow I_B = 0.043mA$$

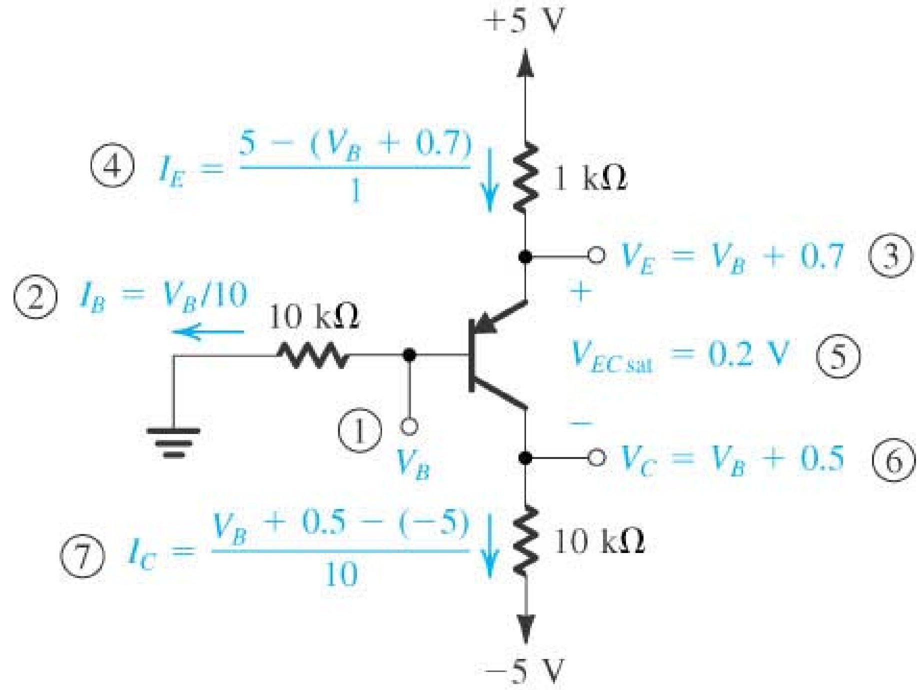
$$I_C = \beta I_B = 4.3mA$$

$$V_C = 10 - I_C R_C = 10 - 4.3m \times 2k = 1.4V$$

Example 5.9 (DC analysis)



(a)



(b)

Assume BJT in active mode :

$$V_E = V_{EB} + V_B$$

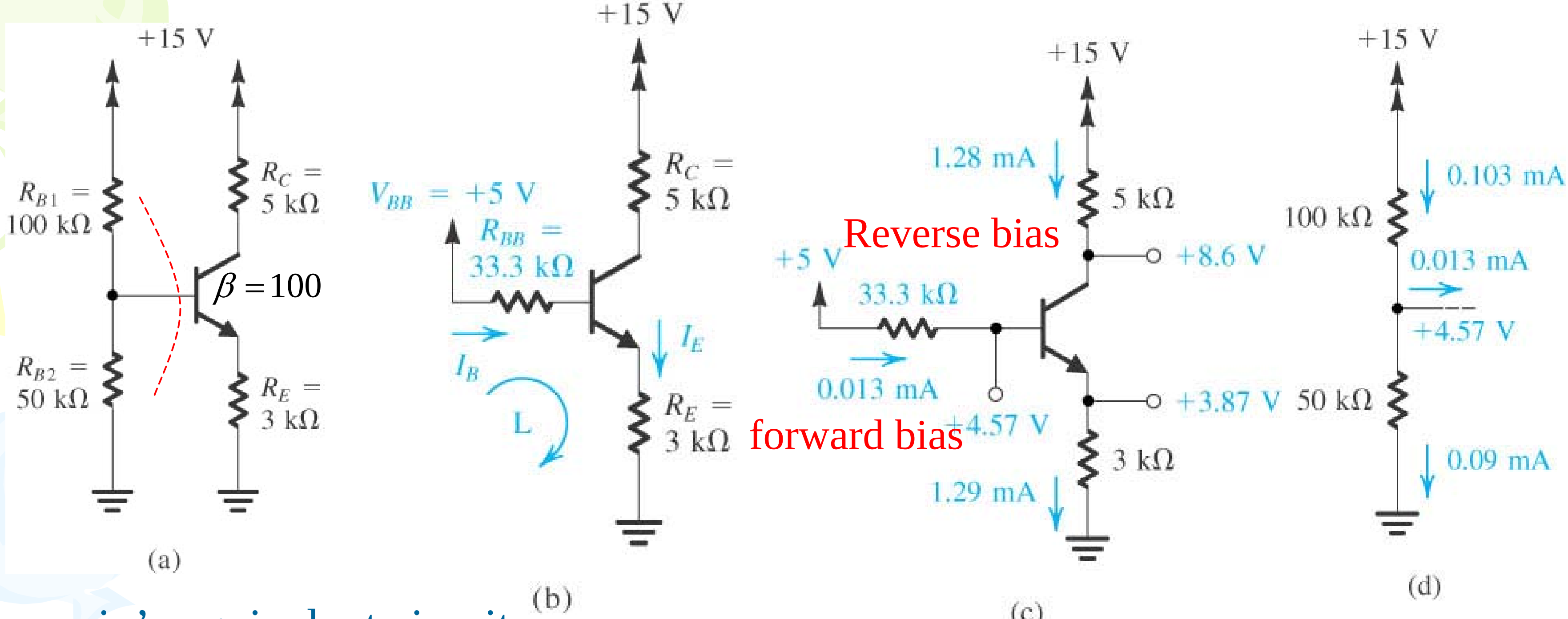
$$R_B \quad large \rightarrow \quad I_B \approx 0$$

$$V_E \approx 0.7V \rightarrow I_E = \frac{5-0.7}{1k} = 4.3mA$$

$$I_C \approx I_E = 4.3V \rightarrow V_C = 10k \times 4.3m - 5V = 38V\,(impossible)$$

$$I_{C(\max)} = 0.5mA \rightarrow V_C = 0V$$

Example 5.10 (DC analysis)



Thevenin's equivalent circuit

$$V_{BB} = 15V \frac{50k}{100k + 50k} = 5V$$

$$R_{BB} = 100k // 50k = 33.3k$$

Assume BJT in active mode :

$$V_{BB} = I_B R_{BB} + V_{BE} + I_E R_E$$

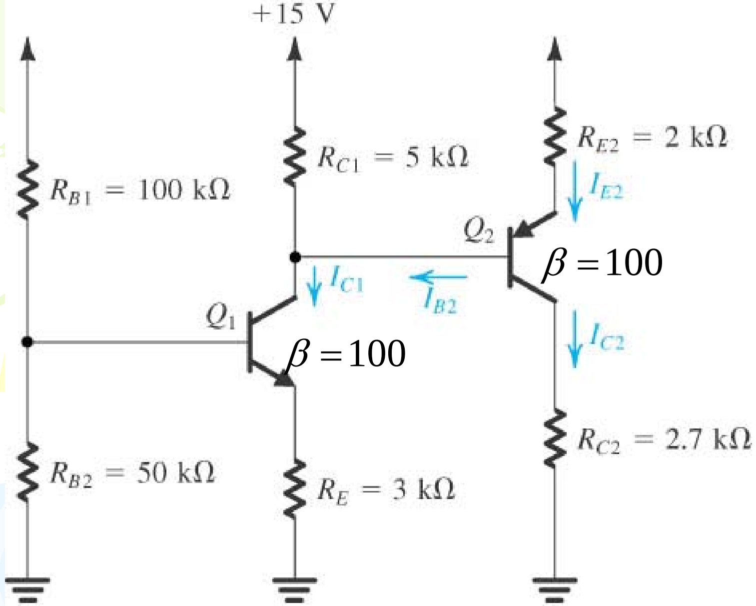
$$V_{BB} = I_B R_{BB} + V_{BE} + (\beta I_B + I_B) R_E$$

$$\Rightarrow I_B = 0.0128mA$$

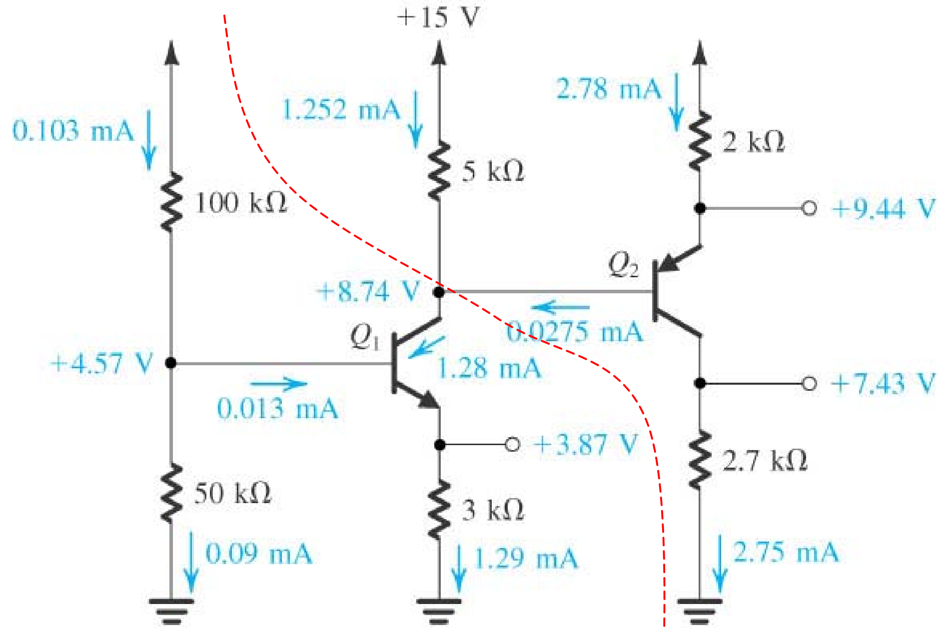
$$\Rightarrow I_E = 101 \times I_B = 1.29mA$$

$$\Rightarrow I_C = 1.28mA$$

Example 5.11 (DC analysis)



(a)



(b)

$$15V = (I_{C1} + I_{B2})R_{C2} + V_{C1} \approx I_{C1}R_{C2} + V_{C1}$$

$$\Rightarrow V_{C1} \approx 8.6V$$

$$V_{E2} = V_{C1} + 0.7V \approx 9.3V$$

$$I_{E2} = \frac{15 - 9.3}{2k} \approx 2.85mA$$

$$I_{C2} = \alpha I_{E2} \approx 2.82mA$$

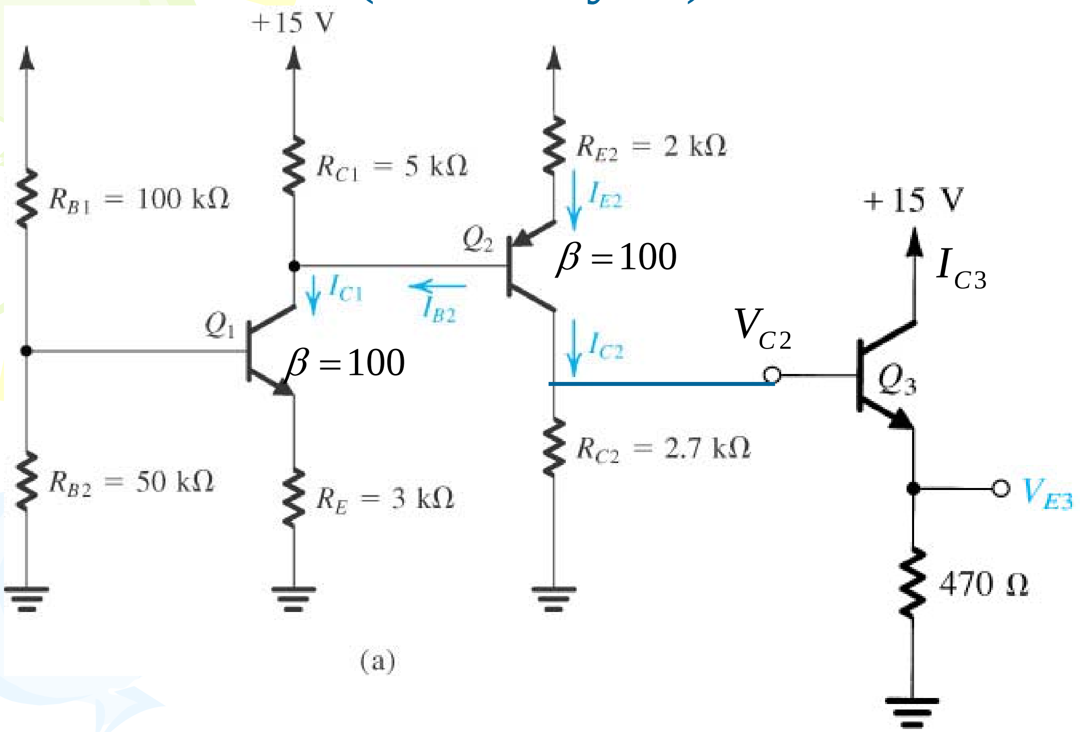
$$V_{C2} = I_{C2} \times 2.7k \approx 7.62V$$

$$I_{B2} = \frac{I_{E2}}{101} \approx 0.028mA$$

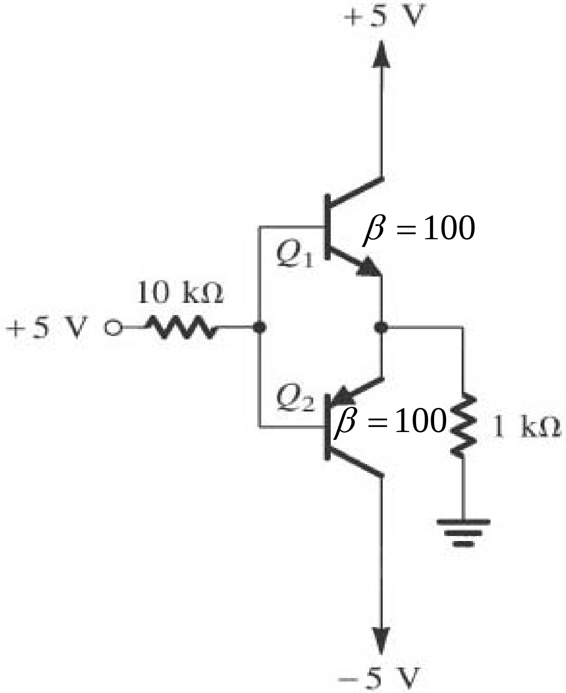
Find correct current by iteration

$$start \quad with \quad I_{B2} = 0.028mA$$

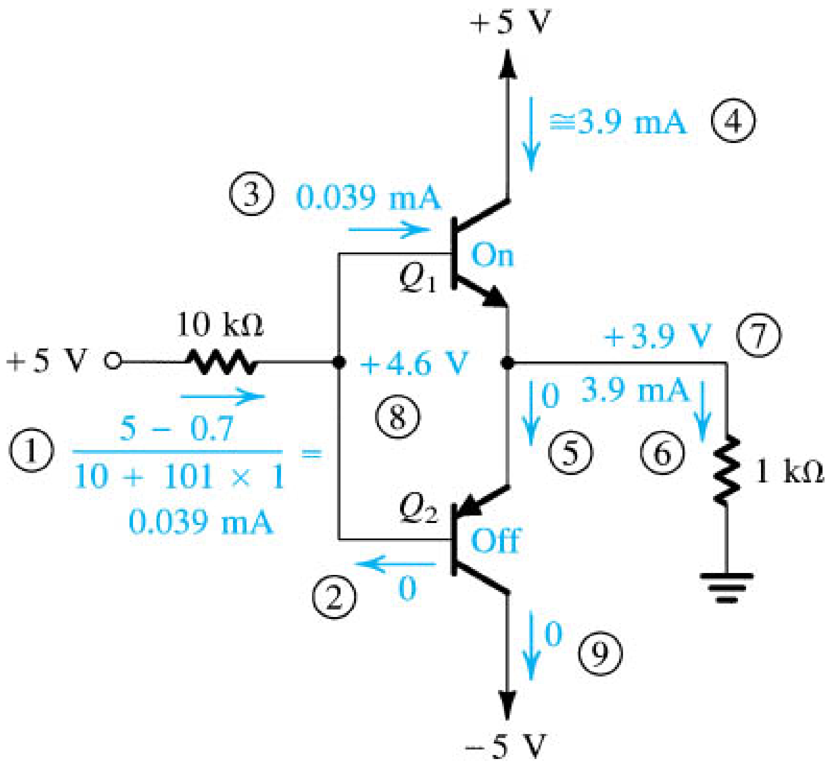
Exercise 5.30 (DC analysis)



Example 5.12 (DC analysis)



(a)



(b)

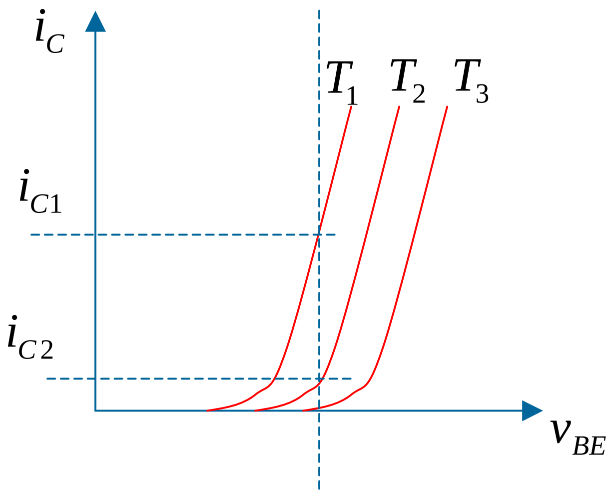
Q1 and Q2 cannot be conducting at same time.
If Q1 ON than Q2 OFF, and vice versa.
Assume Q1 on and Q2 off :

BJT's biasing schemes

1. self-bias
2. Base fixed bias
3. Collector-feedback bias
4. Two power supply version bias
5. Constant current bias

Why we need good biasing scheme?

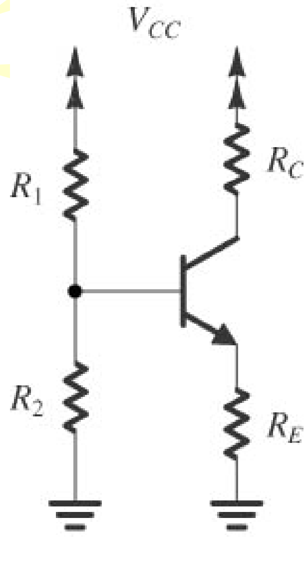
1. Temperature change →Collector biasing current change
2. Device change → biasing current change



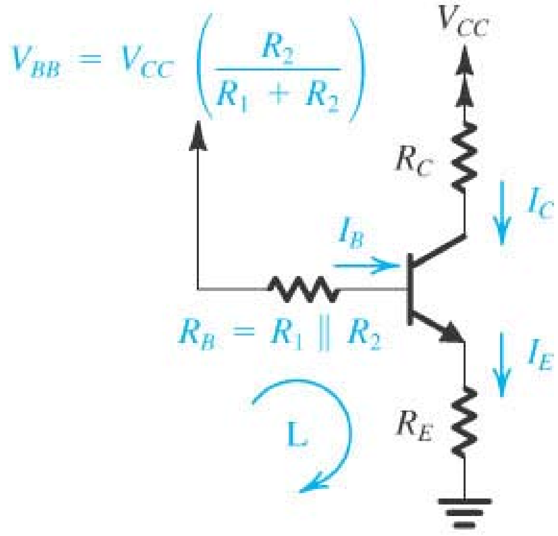
$$i_C = I_S e^{\frac{V_{BE}}{V_T}}$$

$$V_T = \frac{KT}{q} = \frac{1.38\times10^{-23}(^oK)}{1.6\times10^{-19}}$$

1. Self-Bias



(a)



(b)

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

Insensitive to T and β

Constrains:

$$V_{BB} >> V_{BE}$$

$$R_E >> \frac{R_B}{1+\beta}$$

Voltage-divider :

$$R_E >> \frac{R_B}{1+\beta}$$

$$\therefore R_B = \frac{R_1 R_2}{R_1 + R_2}$$

$$\because R_1, R_2 small \rightarrow I_B \uparrow$$

Trade-off

Suggestion:

$$\boxed{(R_1 + R_2) \times 0.1 \times I_E = V_{CC}}$$

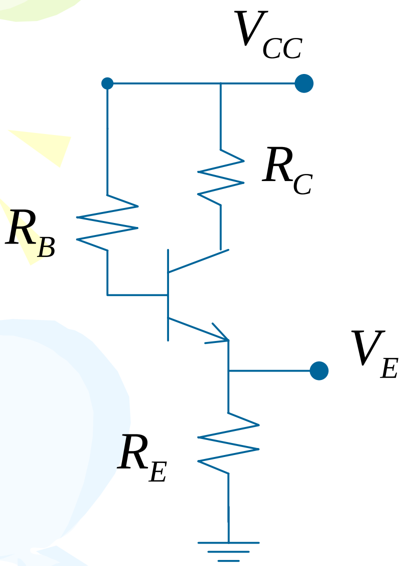
The rule of thumb :

$$V_{BB} = \tfrac{1}{3} V_{CC}$$

$$I_C R_C = \tfrac{1}{3} V_{CC}$$

$$V_{CE} (or V_{CB}) = \tfrac{1}{3} V_{CC}$$

1. Self-Bias (emitter feedback bias)



$$I_E = \frac{V_{CC} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

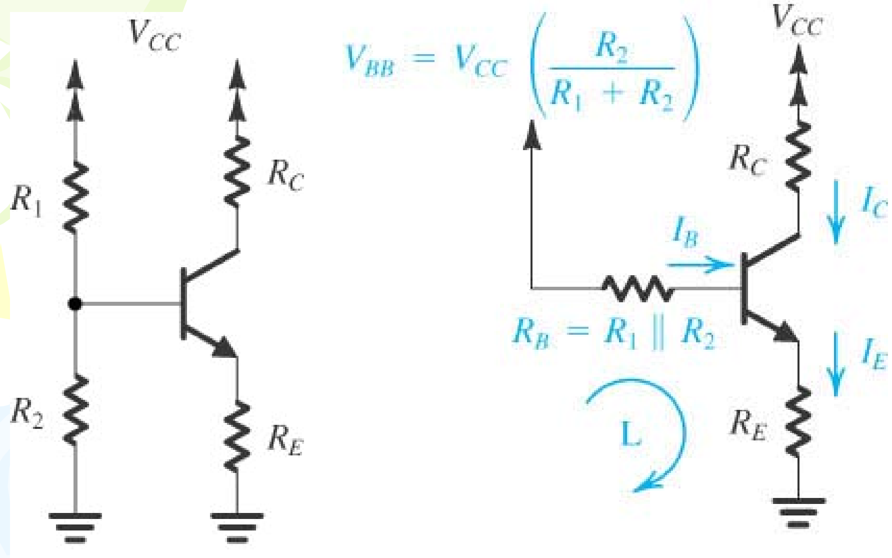
The rule of thumb :

$$V_{BB} = \frac{1}{3} V_{CC}$$

$$I_C R_C = \frac{1}{3} V_{CC}$$

$$V_{CE} (or V_{CB}) = \frac{1}{3} V_{CC}$$

Example 5.13 design the following self bias circuit



(a) (b)

$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

The rule of thumb :

$$V_B = \tfrac{1}{3}12 = 4V$$

$$V_E = 4 - V_{BE} = 3.3V$$

$$R_E = \frac{V_E}{I_E} = \frac{3.3}{1m} = 3.3k$$

$$R_C = \frac{\frac{1}{3}12}{\alpha I_E} = \frac{4}{0.99 \times 1m} \approx 4k$$

given

$$I_E = 1mA$$

$$V_{CC} = 12V$$

$$\beta = 100$$

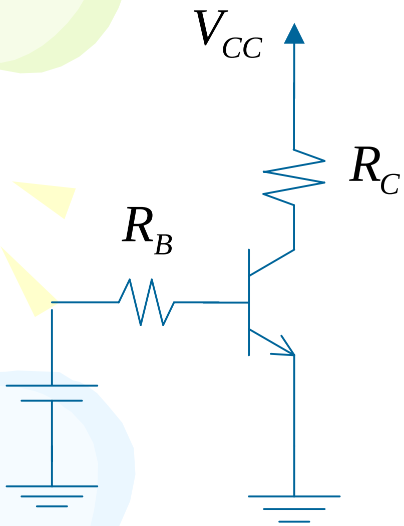
$$(R_1 + R_2) \times 0.1 \times I_E = V_{CC}$$

$$\Rightarrow (R_1 + R_2) \times 0.1 \times 1 = 12 \cdots (a)$$

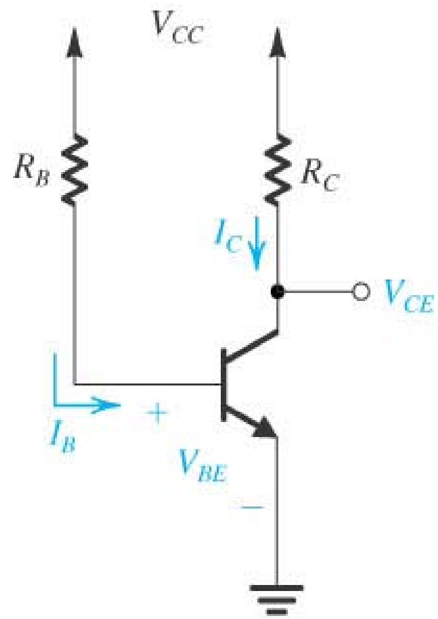
$$V_B = 4V \Rightarrow \frac{R_2}{R_1 + R_2} V_{CC} \cdots (b)$$

$$(a),(b) \Rightarrow \begin{matrix} R_1 = 80k \\ R_2 = 40k \end{matrix}$$

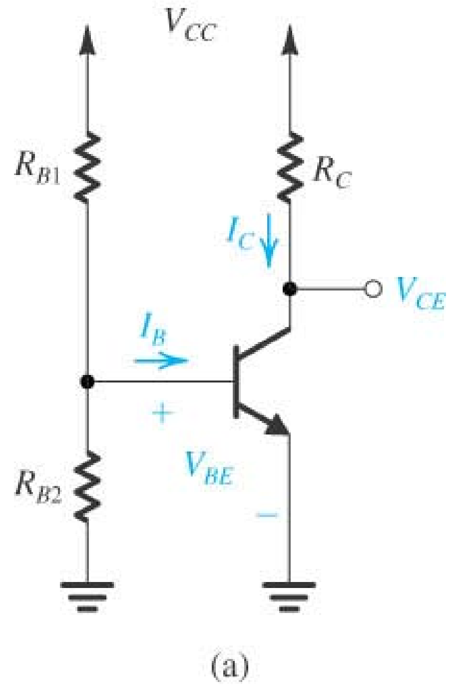
2. Base fixed bias



Type 1



Type 2



Type 3

$$I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B}$$

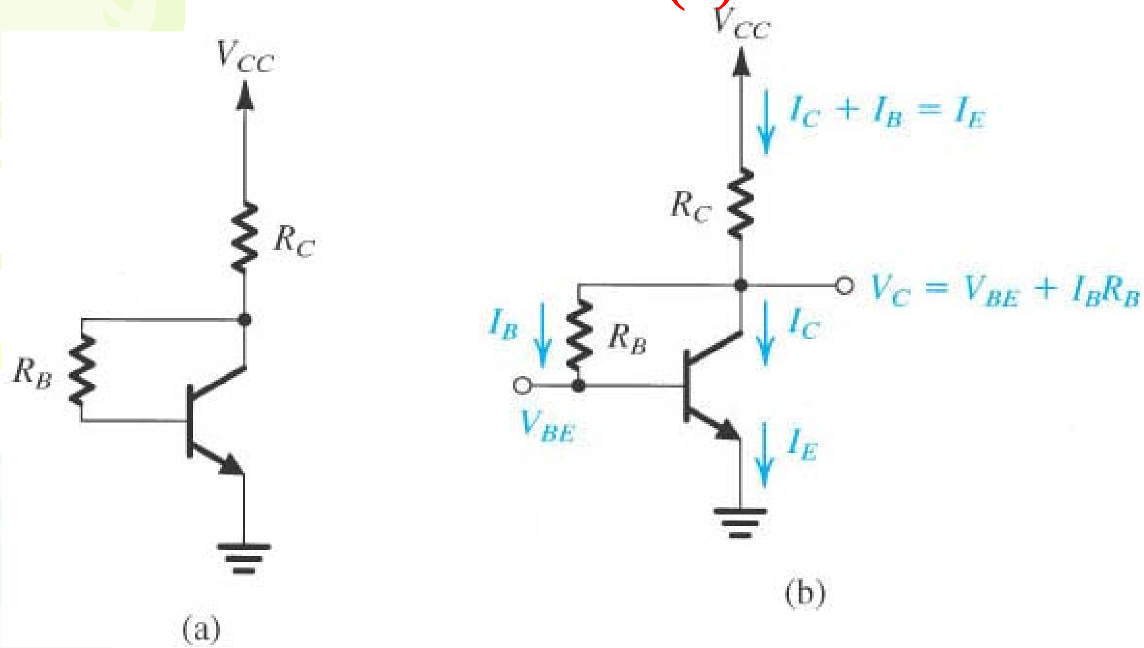
$$I_C = \frac{\beta(V_{CC} - V_{BE})}{R_B}$$

$$I_C = \frac{\beta(V_{BB} - V_{BE})}{R_B}$$

$$R_B = R_{B1} // R_{B2}$$

$$V_{BB} = \frac{R_{B2}}{R_{B1} + R_{B2}} V_{CC}$$

3. Collector-feedback bias (a)



Constrains:

$$R_C >> \frac{R_B}{1+\beta}$$

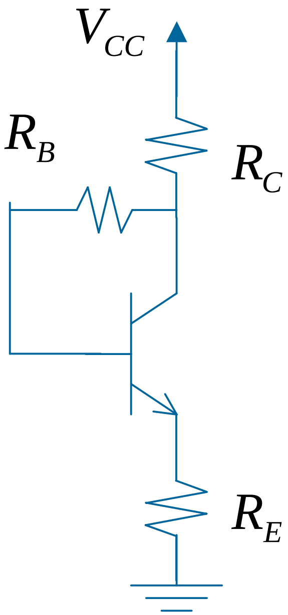
$$V_{CC} = I_E R_C + I_B R_B + V_{BE}$$

$$I_E = I_B + I_C = \frac{V_{CC} - V_{BE}}{R_C + \frac{R_B}{1+\beta}}$$

$$T \uparrow \Rightarrow I_C \uparrow \Rightarrow I_C R_C \uparrow$$
$$\Rightarrow V_{CE} \downarrow \Rightarrow I_B \downarrow \Rightarrow I_C \downarrow$$

Good biasing scheme

3. Collector-feedback bias (b)



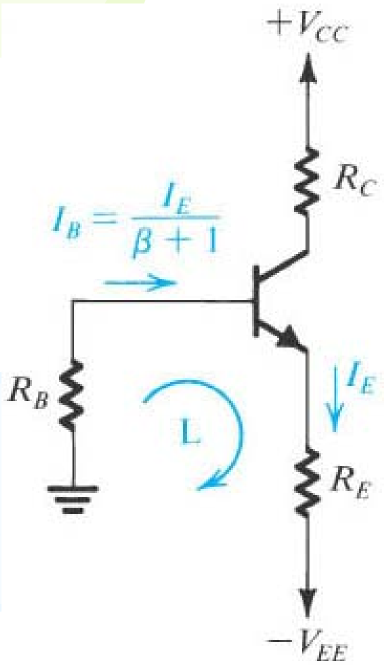
$$V_{CC} = (I_B + I_C)R_C + I_B R_B + V_{BE} + (I_B + I_C)R_E$$

$$I_E = I_B + I_C = \frac{V_{CC} - V_{BE}}{R_C + R_E + \frac{R_B}{1+\beta}}$$

$$\boxed{\begin{array}{l} T\uparrow \Rightarrow I_C\uparrow \Rightarrow I_E\uparrow \\ \Rightarrow V_{CE}\downarrow \Rightarrow I_B\downarrow \Rightarrow I_C\downarrow \end{array}}$$

Good biasing scheme

4. Two-power supply version



$$I_B R_B + V_{BE} + I_E R_E = V_{EE}$$

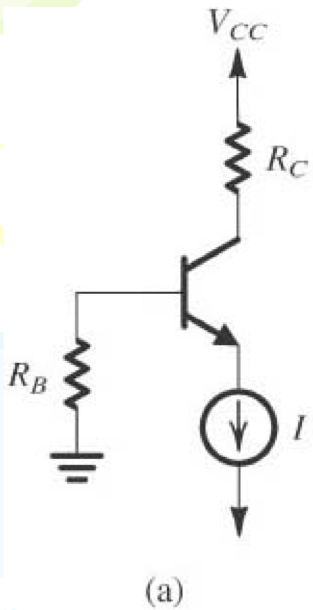
$$\Rightarrow I_E = \frac{V_{EE} - V_{BE}}{R_E + \frac{R_B}{1+\beta}}$$

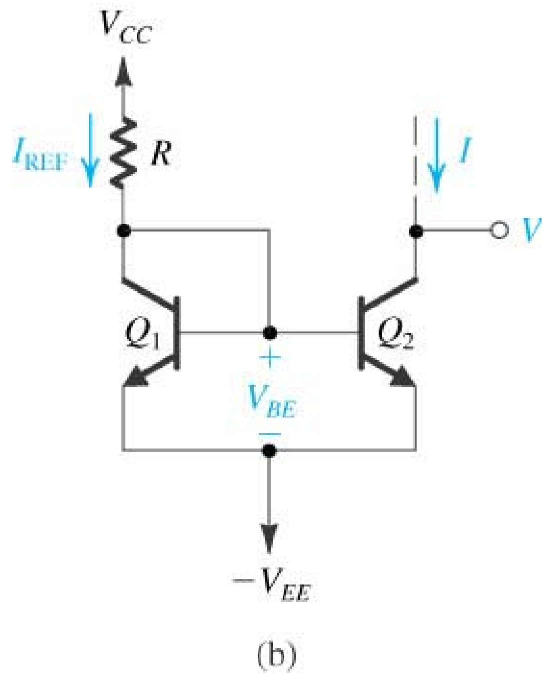
Constrains:

$$V_{BB} >> V_{BE}$$

$$R_E >> \frac{R_B}{1+\beta}$$

5. Constant current bias by Current mirror





$$I_{REF} = I_{C1} + I_{B1} + I_{B2}$$

$$\because Q_1 \equiv Q_2$$

$$\therefore I_{B1} = I_{B2} = I_B$$

$$I_{REF} = I_{C1} + 2I_B = (\beta + 2) I_B$$

$$I = I_{C2} = I_{C1} = (\beta + 2) I_B$$

$$\frac{I}{I_{REF}} = \frac{\beta}{(\beta + 2)} \approx \beta$$

$$I_{\mathrm{Re}\,f} = \frac{V_{CC} - (-V_{EE}) - V_{BE}}{R}$$

$$I = I_{\mathrm{Re}\,f} = \frac{V_{CC} + V_{EE} - V_{BE}}{R}$$